DRAFT PERFORMANCE WORK STATEMENT

STRUCTURES, MATERIALS, AERODYNAMICS, AEROTHERMODYAMICS, AND ACOUSTICS RESEARCH AND TECHNOLOGY (SMAAART 2)

1.0 SCOPE AND OBJECTIVES

1.1 This performance work statement (PWS) defines the technical scope to support research and technology development for aerospace vehicles that support NASA's goals in the areas of: Advanced Materials and Structural Systems; Aerodynamics, Aerothermodynamics, and Acoustics; Systems Analysis and Concepts; Entry, Descent, and Landing; Measurement Systems; and Flight Critical and Intelligent Flight Systems.

1.2 The scope of this PWS is intentionally broad, to cover the breadth of NASA's aerospace research and development goals. Task orders issued against this PWS will range in maturity from basic research, tool and technology development through integrated flight demonstrations. Vehicle concepts and performance conditions will fall within the speed regimes of subsonic through hypersonic atmospheric flight through continuum and rarified flow fields.

1.3 The contractor shall furnish all personnel, facilities, equipment, material, supplies, and services, except as may be expressly set forth in the contract task orders as Government furnished, and otherwise do all things necessary to, or incident to perform and provide the work efforts described in this Exhibit A. The contractor shall perform task orders that are issued by a NASA Contracting Officer. This contract may be used to support all NASA Centers that require work within the scope of this PWS.

2.0 ADVANCED MATERIALS AND STRUCTURAL SYSTEMS (TECHNICAL AREA 1)

Task orders will be written to support basic and applied research, technology development, systems analyses, and trade studies in advanced materials and structural systems. Research areas of interest include, but are not limited to: advanced materials and processing; durability, damage tolerance, and reliability; structural mechanics and concepts; and structural dynamics. Research will be both analytical and experimental in order to develop and study advanced materials and complex structures, at length scales ranging from atomistic to full-scale integrated structural systems, under static and dynamic mechanical and thermal fatigue loading conditions. Research will employ industry-standard nondestructive evaluation practices in support of manufacturing and testing, where needed.

2.1 Advanced Materials and Processing

The contractor shall conduct basic and applied research in materials and processing, develop advanced materials, and integrate them into aerospace systems. Materials and processing research includes, but is not limited to: computational modeling and analysis; experimental synthesis; processing and fabrication; additive manufacturing; materials characterization; environmental exposure; and testing to establish correlations among structure, processing, environmental exposure, and material property variables.

The contractor shall employ industry-standard methods and newly-developed methods for processing, manufacturing and assembly.

2.2 Durability, Damage Tolerance, and Reliability

The contractor shall conduct research in the stability, strength, damage tolerance, and structural integrity of aerospace materials and structures. The contractor shall identify structural deformations and failure modes, develop and apply verified and validated analytical and computational failure analyses, and predict linear and nonlinear structural response phenomena in undamaged and damaged structures. The contractor shall develop and validate new static and dynamic test techniques. The contractor shall characterize the constitutive relationships for advanced materials and their mechanics for structural applications. The contractor shall develop computationally efficient, integrated design tools for assessing the radiation environment, risk, and effectiveness of multifunctional radiation shielding materials.

2.3 Structural Mechanics and Concepts

The contractor shall develop efficient structural concepts for future aerospace structures and space transportation systems that exploit the benefits of advanced material systems.

2.3.1 Integration of New Materials

The contractor shall integrate new material systems into structural designs, and manufacture structural subcomponents and components for characterization and testing of larger-scaled test articles.

2.3.2 Advanced Design Methods

The contractor shall develop advanced design methods that reduce design cycle time; perform sizing, optimization, and uncertainty; and account for material, thermal, and structural interactions.

2.3.3 Structural and Thermal Analysis and Testing

The contractor shall study thermal and structural behavior and their interactions. The contractor shall develop, apply, and validate analysis methods and structural performance by conducting thermal and structural experiments for elements, components, and large-scale test articles, subject to static and time-varying mechanical loads and thermal loads ranging from cryogenic (-400°F) to reentry (4000°F) temperatures.

2.4 Structural Dynamics

The contractor shall conduct analytical and experimental research for the purpose of developing and validating improved methods to predict, verify, and control the dynamic responses of complex aerospace structures, and to confirm the validity of approaches by conducting tests on full-scale structures, structural elements, and scaled structural models.

3.0 AERODYNAMICS, AEROTHERMODYNAMICS, AND ACOUSTICS (TECHNICAL AREA 2)

Task orders will be written to support basic and applied research, technology development, systems analyses, and trade studies in aerodynamics, aerothermodynamics, and acoustics related to aerospace vehicles. Research areas of interest include, but are not limited to: configuration aerodynamics; computational modeling and simulation; flow physics and control; aerothermodynamics; hypersonic airbreathing propulsion; vehicle noise prediction and control; aeroelasticity; and model systems. Research will be experimental and computational in nature, investigating vehicle configurations for atmospheric flight including all classes of aircraft, at speed regimes ranging from subsonic through hypersonic speeds, in Earth’s and other planetary atmospheres. Research may span a range of maturity levels, from fundamental tool and technology development through integrated flight demonstrations.

3.1 Configuration Aerodynamics

The contractor shall conduct research on advanced configuration concepts for all classes of aircraft at subsonic through hypersonic speeds. The contractor shall conceive and evaluate innovative aircraft planform shapes, control effectors, propulsion systems, and propulsion system installations.

3.1.1 Advanced Configurations

The contractor shall evaluate and optimize advanced configurations relative to metrics including, but not limited to: noise, emissions, fuel burn, stability, and maneuverability. This research includes, but is not limited to: design and analysis for reduced sonic boom, and the complex flow physics and integrated aerodynamic characteristics of advanced configuration concepts. The contractor shall conduct research to optimize external shape, develop and apply active and passive configuration shaping, active and passive flow control, thrust vectoring, and advanced propulsion systems and propulsion installations.

3.1.2 Integration and Interaction of Aircraft Components

The contractor shall conduct research to understand and optimize the mutual interference effects among aircraft components including, but not limited to the wing, fuselage, propulsion system, and external stores. The contractor shall perform research supporting integration of the propulsion system within the airframe of advanced vehicle concepts.

3.2 Computational Modeling and Simulation

The contractor shall conduct research in computational modeling and simulation of fluid dynamic and acoustic phenomena of complex aerospace systems, involving flow across the flight regimes from incompressible to hypersonic. The contractor shall research, develop, and apply analytical and numerical methods, and extend existing computational methods to analyze vehicle components and complex vehicle configurations for a variety of applications, including, but not limited to: airframe and engine noise prediction and control; turbulence and transition modeling, validation, and control; chemically reacting flows and flow control; time-dependent flow fields for flow control device design; vehicle stability and control; vehicle aeroelastic stability prediction; and vehicle vibro-acoustic prediction and control. The contractor shall conduct research in post-processing and visualization of simulation results.

3.2.1 Linear and Nonlinear Modeling

The contractor shall utilize the full range of mathematical equations, from linearized to fully non-linear equations, for computational modeling and simulation of fluid dynamic and acoustic phenomena of complex aerospace systems. The contractor shall develop and validate steady and unsteady solutions to the Reynolds-Averaged Navier-Stokes equations (RANS), large eddy simulations (LES), and hybrid RANS/LES simulations. The contractor shall conduct research in grid generation, including, but not limited to: rapid and robust analysis and design of adaptive unstructured grids, and fluid dynamics/aeroacoustic equation solution methods for structured and unstructured grid topologies.

3.2.2 Multi-Disciplinary Optimization

The contractor shall research, develop, and apply optimization method to solve design problems. The contractor shall use combinations of design variables and constraints, to achieve the most optimized solutions, and incorporate them into the final design.

3.2.3 High-Performance Computing Architectures

The contractor shall apply massively parallel and distributed computers for affordable computations and high-performance applications for challenge problems. The contractor shall explore new and evolving high-performance computing architectures, including, but not limited to: central processing units, graphical processing units, high-speed interconnections, high-speed and/or parallel file systems, and new programming paradigms for these machines.

3.3 Flow Physics and Control

The contractor shall conduct experimental and computational research to enhance the knowledge and understanding of the physics underlying boundary layer transition, active and passive flow control, three-dimensional flow physics, turbulence, and vortical and separated flows. The contractor shall apply this understanding to develop advanced computational and analytical methods to predict boundary layer transition and to develop techniques for controlling viscous fluid flows. The contractor shall conduct experiments to obtain detailed flow field and surface data to validate computational methods.

3.4 Aerothermodynamics

The contractor shall conduct research to understand and predict the aerothermodynamics of flow fields associated with aerospace vehicles. The contractor shall develop rapid, high fidelity computational and experimental tools that can be used for vehicle assessment and technology advancement. The contractor shall develop technologies that address aerothermodynamic design issues and enable, enhance, and optimize vehicle performance for access to space and planetary entry.

3.5 Hypersonic Airbreathing Propulsion

The contractor shall conduct multidisciplinary research to develop advanced technologies for hypersonic airbreathing propulsion systems, with a focus on airframe-integrated engine concepts having high performance over a wide range of flight Mach numbers. The contractor shall conduct research to develop and validate integrated multidisciplinary methods for design and analysis based on fundamental physics and phenomenological models to represent the effects of turbulence, mixing, finite-rate reactions, fuel injection, and geometry on ignition, combustion and thrust performance across the speed regime from takeoff to orbital velocity. The contractor shall utilize experimentally verified analysis methods, appropriate ground and flight test data, or conduct tests of complete subscale and large-scale engines, to assess and improve integrated engine and aero-thermo-structural performance. The contractor shall develop innovative experimental techniques, diagnostics, and tools for testing airframe-integrated engines in ground test facilities. The contractor shall design and build specialized facility hardware to support high-Mach wind tunnel tests.

3.6 Vehicle Noise Prediction and Control

The contractor shall conduct research in noise generation mechanisms, noise propagation, community response, and noise reduction techniques for all classes of aircraft, spacecraft, and launch vehicles. The contractor shall develop methods for predicting acoustics and flow fields and their interaction, including propulsion/airframe aeroacoustics. The contractor shall conduct research to understand interior noise and vibration and its effects on aerospace structures, payloads, passengers and crew, and develop active and passive concepts for interior noise control. The contractor shall conduct research to understand, predict, and control the response of vehicle structures to acoustic loads to avoid acoustic fatigue. The contractor shall conduct research to understand, predict and control the dynamic pressure loads and vibration associated with launch vehicle launch noise and vibration, including, but not limited to: launch blast, maximum dynamic pressure, and transonic flight regimes. The contractor shall conduct research to understand and mitigate the impact of aircraft noise on communities and the environment during all phases of flight, including, but not limited to, vehicle configurations and flight path trajectories with reduced noise impact.

3.7 Aeroelasticity

The contractor shall conduct research to understand and predict aeroelastic phenomena of aerospace vehicles and subsystems. The contractor shall develop, evaluate, and validate aerodynamic and structural control concepts that employ smart materials or aerodynamic control surfaces for suppressing aeroelastic response and alleviating loads and vibration. The contractor shall develop and design flutter prevention methods through analysis and aeroelastically-scaled model tests.

3.8 Model Systems

The contractor shall perform research to develop test articles and instrumentation systems, including, but not limited to: electromechanical systems, discrete measurement systems, and sub-scale flight vehicles that integrate complex hardware and instrumentation systems. The contractor shall conduct research to assess and improve the capabilities of scaled model systems. The contractor shall develop model systems for a variety of applications, including, but not limited to: morphing and dynamic control for test articles, and characterization and integration of sensors including, but not limited to strain, force, and angle-of-attack.

4.0 SYSTEMS ANALYSIS AND CONCEPTS (TECHNICAL AREA 3)

Task orders will be written to support systems analyses, trade studies, and multidisciplinary methods applied to aerospace concepts and systems to enable NASA to make informed technical, programmatic, and budgetary decisions. Research areas of interest include: complex mission level concepts; vehicle systems architectures; technology assessments; subsystems integration; operational factors; and systems analysis tools.

4.1 Complex Mission Level Concepts

The contractor shall provide analyses supporting the definition and refinement of broad aerospace transportation concepts, including, but not limited to: multiple-mission campaigns; multi-phase missions; and many-vehicle system management (complex airspace). Example analyses include, but are not limited to: improved gate-to-gate mobility in the air transportation system; maintained and improved safety of aircraft in an increasingly complex airspace system; identification and assessment of architecture requirements for space exploration; integration of human exploration campaigns with mission design and campaign analysis; and identification and prioritization of capability and technology requirements.

4.2 Vehicle Systems Architectures

The contractor shall perform systems analyses and develop concepts for revolutionary and evolutionary aerospace vehicle system architectures and configurations, including, but not limited to: design and analysis to estimate standard vehicle performance metrics including, but not limited to mass, physical dimensions, mission performance and thermal management, and integration of airframes with propulsion systems.

4.3 Technology Assessments

The contractor shall perform objective technology assessments to quantify the benefits of advanced technologies on aerospace vehicle performance and related Figures of Merit (FOMs). This effort includes, but is not limited to: the collection and compilation of technology data, development of a baseline concept or system upon which technology trades will be made, identification of technology performance requirements, development of fast-acting surrogate models of vehicle discipline analyses to be used in probabilistic analyses, and probabilistic analyses and quantification of technology impact on FOMs.

4.4 Subsystems Integration

The contractor shall perform systems analyses and trade studies for integration of aerospace vehicle subsystems, including, but not limited to: structural subsystems, advanced propulsion concepts, thermal protection systems, radiation shielding, communications, sensors, power, and thermal subsystems. The contractor shall perform systems analysis and trade studies for spacecraft payload integration, including, but not limited to: layout, packaging, sizing, and closure.

4.5 Operational Factors

The contractor shall analyze operational factors of aerospace systems, including, but not limited to: life cycle cost; reliability; operability of different flight regimes and Earth to orbit launch vehicle designs and related systems; and trade studies on such designs producing deterministic and probabilistic results. The contractor shall perform reliability analyses to determine probability of occurrence estimates for critical mission end-states including, but not limited to: loss of mission and loss of vehicle. The contractor shall map resource utilization to mission phases, provide analytical support for life-cycle-cost methods and costing of mission elements and architectures, and perform affordability analyses.

4.6 Systems Analysis Tools

The contractor shall assess existing analytical capabilities and tools used to design and analyze aerospace concepts and systems, identify improvements necessary to support system analysis and concept development for a broad range of aerospace applications, and support the enhancement of those analytical tools. The contractor shall develop and deliver analytical methods and tools as required to analyze, perform trade studies on, visualize, and archive aerospace design concepts.

5.0 <u>ENTRY, DESCENT, AND LANDING (TECHNICAL AREA 4)</u>

Task orders will be written to support basic and applied research, technology development, systems analyses, and trade studies in Entry, Descent, and Landing (EDL) technologies and mission architectures. Research areas of interest include: EDL concept development; enabling technologies for EDL; and analysis and testing of integrated EDL test articles and vehicle systems.

5.1 EDL Concept Development

The contractor shall conduct systems analyses and trade studies to determine the potential benefits of different concepts for EDL systems. The contractor shall perform analyses of payload packaging concepts and the mechanical, structural, thermal, aerodynamic, and aerothermodynamic characteristics of EDL systems. The contractor shall design, fabricate, and integrate subsystems, including, but not limited to:

packaging of a deployable aeroshell and a flexible thermal protection system (TPS). The contractor shall perform detailed analyses of flight mechanics, systems, and missions for Earth, lunar and planetary exploration. Analyses shall include, but not be limited to, detailed analysis of the aeroassist (AA) element of the missions, including aerobraking, aerocapture, and EDL. The contractor shall perform design studies to determine optimum vehicle shapes, entry trajectories, and guidance and control algorithms for all types of AA missions.

5.2 Enabling Technologies for EDL

The contractor shall develop revolutionary and evolutionary EDL technologies, including, but not limited to: advanced rigid and flexible materials (structural, nonstructural, and TPS); rigid and deployable structures; aeroassist techniques; inflation systems; guidance, navigation, and control; pyrotechnics; and flight mechanics.

5.3 Analysis and Testing

5.3.1 The contractor shall develop and fabricate test articles for ground and flight testing. The contractor shall conduct high-fidelity structural and thermal analysis and testing on all test articles. The contractor shall perform ground- based proof-of-concept testing at the integrated system level in relevant environments.

5.3.2 The contractor shall develop high-fidelity 3- and 6-DoF (Degree of Freedom) flight simulations, to determine nominal performance, perform sensitivity analyses, and assess mission element risks. The contractor shall provide recommendations, enhancements, augmentations, and other modifications to simulation software and EDL systems models to assess EDL system performance. The contractor shall provide EDL engineering analyses, animations, and video productions to support software tuning for ground-based and flight demonstrations.

5.3.3 The contractor shall: provide entry body static aerodynamic coefficients and dynamic stability derivatives for trajectory simulation and vehicle performance evaluation from hypervelocity (at atmospheric interface), through supersonic and transonic regimes, to subsonic conditions; determine entry body trim angle-of-attack and trim lift-to-drag ratio values, across speed regimes (hypervelocity through subsonic) and for flow fields from rarefied to continuum; estimate entry vehicle heat flux spatial distributions and temporal profiles, and the resultant integrated heat loads, for specified trajectories; and provide visualization of flow field parameters around the entry body along the entry trajectory.

6.0 MEASUREMENT SYSTEMS (TECHNICAL AREA 5)

Task orders will be written to support basic and applied research, technology development, systems analyses, and trade studies in measurement systems for aerospace applications. Research areas of interest include, but are not limited to: nondestructive evaluation; *in situ* sensors and systems; remote sensing, measurement, and diagnostics systems; sensors, transducers, imaging arrays, and emission sources; large and high-speed data management; and physics-based modeling and simulation of sensors and measurement systems.

6.1 Nondestructive Evaluation

The contactor shall conduct research and technology development in quantitative nondestructive evaluation (NDE) sciences, methods, and systems for characterization of aerospace materials and structures in the laboratory and in the field. Applicable nondestructive measurement technologies include, but are not limited to: ultrasound, acoustic emission, acoustic microscopy, electromagnetics, optics, radiography, fiber optics, computed tomography, terahertz imaging, and thermography. The contractor shall develop prototype sensors and transducers, instrumentation, systems, and application techniques, addressing material/structural types found in current and next-generation aerospace systems, including, but not limited to: polymeric and metallic matrix composites, sandwich and stiffened structures, carbon-carbon and ceramic materials, advanced metals, 3D printed and other built-up structures, nanotube-based composites, and smart materials and structural systems.

6.2 *In situ* Sensors and Systems

The contractor shall conduct research and development of *in situ* sensors and sensor systems for aerospace vehicle applications. *In situ* sensors and sensor systems include, but are not limited to, those for the application areas of: monitoring the structural, dynamic, aerodynamic, aerothermodynamic, and electromagnetic state of an aerospace vehicle, measurement of combustion and other chemically reactive processes, and measurement of engine propulsion, emissions, and performance characteristics. *In situ* sensor systems of interest include, but are not limited to: distributed sensors (e.g., fiber optic sensors) and sensor arrays, embedded sensors and actuators, and discrete sensors. The contractor shall develop methods for miniaturization of sensors and measurement systems to achieve low mass, low volume, and low power consumption. The contractor shall perform systems analyses to optimize placement of *in situ* sensors for particular applications.

6.3 Remote Sensing, Measurement, and Diagnostics Systems

The contractor shall conduct research and development of experimental measurement and sensing techniques for aerospace research and development applications. The contractor shall develop a variety of advanced sensing technologies, methods and/or systems ranging from laser-based diagnostics, to analytical chemistry, to optical physics, to advanced sensors and actuators. The contractor shall conduct research aimed at discovering and developing techniques (e.g., femtosecond laser electronic excitation and tagging [FLEET]), applicable in a wind tunnel or free flight environments, which will enable the measurement and quantification of the aerodynamic properties associated with advanced vehicle concepts, in addition to determining optical properties of materials and utilizing optical/laser systems for exploration, rendezvous and docking, hazard avoidance, and Earth and planetary science studies.

6.4 Advanced Sensors, Transducers, Arrays, and Emission Sources

The contractor shall conduct research and technology development in advanced sensors, transducers, arrays and devices, and emission sources utilizing existing and emerging technologies including, but not limited to: nanotubes, quantum dots, advanced optical fibers, nonlinear optical materials, and advanced semiconductor manufacturing processes such as Micro-Electrical Mechanical Systems (MEMS) and Micro-Optical-Electrical Mechanical Systems (MOEMS). The contractor shall develop custom multiple-element array sensors and transducers, including, but not limited to: ultrasonic, eddy current, optical, and other electromagnetic technologies.

6.5 Large and High-Speed Data Management

The contractor shall develop and apply algorithms and approaches for off-line or real-time data reduction, processing, and analysis of large data sets and parallel, high-speed data streams to provide manageable output for human, semi-automated, or automated interpretation. Safety assurance for large high-performance aerospace vehicles will require high-resolution NDE scans, using multiple measurement technologies, which will yield large sets of data. Furthermore, sensors distributed through a vehicle to monitor the state of its structure and systems and video and other sensing systems used to characterize the environment of a vehicle in flight will produce large quantities of data (e.g., multiple terabytes) at extremely high information rates (e.g., multiple high-definition video feeds).

6.6 Physics-Based Modeling and Simulation

The contractor shall develop physics-based theoretical, analytical, and/or computational models for applications to include, but not be limited to: modeling and simulation to aid in design of sensors and transducers, and modeling and simulation of the interaction of sensors and transducers with materials/systems under test to aid with design of measurement techniques.

7.0 FLIGHT CRITICAL AND INTELLIGENT FLIGHT SYSTEMS (TECHNICAL AREA 6)

Task orders will be written to support basic and applied research, technology development, systems analyses, and trade studies in airborne and ground-based systems critical to flight safety, management, and control.

7.1 Crew Systems and Aviation Operations

This work area includes, but is not limited to: integrated flight deck systems; aircraft self-separation and distributed air traffic management; atmospheric hazard awareness and avoidance; situation awareness assessment; synthetic vision; human-machine interface; and human-centered design. These research areas investigate aviation safety and airspace capacity issues including, but not limited to, controlled flight into terrain (CFIT), loss of control in flight, runway incursions, high density air traffic operations, air- and ground-based traffic management, all-weather operations, terrain-impacted navigation, detection and accommodation of wake turbulence and other atmospheric hazards to aviation, and operation of remotely piloted and autonomous aircraft.

7.1.1 Situational Awareness – Flight Crew

The contractor shall research, develop, and evaluate technologies, methods and procedures to improve flight crew situational awareness for Next Generation Air Transportation System (NextGen) operations.

7.1.1.1 Real-time Information: The contractor shall develop technologies and methods that provide real-time information, electronically, to flight crews (airborne or ground-based) to improve their situation awareness. Types of real-time information include, but are not limited to: current position in four dimensional space; traffic locations and identity; terrain and obstacle locations; hazardous weather location and type; flight path or surface route information; air traffic control (ATC) instructions; and alerts of impending or potentially hazardous situations.

7.1.1.2 Flight Deck Displays and Interface Concept: The contractor shall research, develop, and evaluate display concepts and human machine interfaces that reduce uncertainties associated with real-time information presentation. A human centered design approach shall be employed by the contractor.

7.1.1.3 Communication, Navigation, and Surveillance Infrastructure Technologies: The contractor shall develop communication, navigation, and surveillance infrastructure technologies required to acquire, process, and disseminate situation awareness information.

7.1.1.4 Human-in-the-loop Experimentation: The contractor shall design and conduct human-in-the-loop (HITL) experiments in simulation and in flight test environments, including data analysis and publication of results.

7.1.2 Situational Awareness – Air Traffic Control (ATC)

The contractor shall research and develop technologies and methods to increase air traffic control situation awareness, including, but not limited to: strategic and tactical collaborative decision making; seamless surveillance; controller-pilot data link communications (CPDLC); and alerting of flight crew path/route deviations.

7.1.3 Requirements for Human Subject Experimentation

The contractor shall complete all documentation and meet all requirements to conduct experimentation with human subjects, in accordance with NASA procedural requirements (available at the NASA Online Directives Information System http://nodis.hq.nasa.gov/). For flight testing, the contractor shall perform all analyses and develop all documentation necessary to obtain safety authority approval as determined by the appropriate NASA boards. This includes experiments flown on aircraft owned or leased by NASA, the contractor, or subcontractor funded by NASA.

7.2 Safety-Critical Aviation Systems

The contractor shall develop and demonstrate methods, techniques, and tools for the design, verification, validation, and certification of safety-critical systems. This work area includes, but is not limited to: mathematical proof-of-safety properties for software and hardware; formal safety analysis; formal verification; hardware and software verification; system and subsystem validation; system safety assurance; fault tolerance; fault modeling and emulation; architecture concepts to improve system robustness to disturbances; vehicle health management; commercial-off-the-shelf technology in safety-critical systems; complexity modeling and management; integrated modular avionics; requirements analysis for strategic and tactical decision making among distributed computational and/or human elements; and airworthiness and system safety for unmanned aircraft, autonomous, and robotic systems.

7.2.1 Design Integrity

The contractor shall develop and demonstrate methods, techniques, and tools for the design, verification, integration, validation, and certification of complex and highly integrated mission- and life-critical systems. This research area includes, but is not limited to: Formal Methods (e.g., theorem proving, model checking, and static analysis); safety assurance of complex systems; and design and assessment methods and techniques for the Validation & Verification of complex systems (e.g., compositional verification, static analysis methods, model-based development, and numerical analysis).

7.2.2 System Safety Assurance

The contractor shall develop and demonstrate methods, techniques, and tools that provide a consistent and comprehensive approach to system safety for software-intensive systems, regardless of domain (airborne/ground-based/space-based, manned/unmanned). This research includes, but is not limited to: identification and assessment of safety-related requirements; software assurance and certification; safety-related arguments and evidence; airworthiness and systems safety; and the integration of formal, semi-formal, and informal evidence within coherent safety arguments.

7.2.3 Operational Integrity

The contractor shall develop and demonstrate new analytical, architectural, and testing capabilities necessary to meet the high level of integrity required for safely deploying a complex system of systems technologies. This research includes, but is not limited to: architectural principles for redundancy management and fault-tolerance; modeling of faults, failures, disturbances, and degradation; and integrated systems health management.

7.3 Flight Critical Systems Analysis and Assessment

This work area includes, but is not limited to, performance of systems analysis and assessment, and participation on working groups and standards-setting committees in support of airborne and ground-based systems that are critical to flight safety, management, and control.

7.3.1 Systems Analysis and Assessment

The contractor shall conduct systems analysis, conceptual design studies, trade studies, and technology assessments for flight critical aerospace systems. This work area includes, but is not limited to: requirements analysis, design and analysis of systems concepts, assessment of alternatives, cost-benefit studies, experimental system design, system verification and validation, life-cycle planning, assessment of technical alternatives, flight testing and simulation, and the defining of technology requirements. The contractor shall perform all analyses and develop all documentation necessary to obtain safety authority approval as determined by the appropriate NASA boards. This includes, but is not limited to, experimental flight system(s) flown on aircraft owned or leased by NASA, the contractor, or subcontractor funded by NASA.

7.4 Flight Dynamics, Guidance, Control, and Intelligent Flight Systems

This work area includes, but is not limited to: attached and separated-flow aerodynamics; static and dynamic stability; control effector characteristics; dynamic modeling methods; flight-control law effects; flying and handling qualities; agility and maneuverability; out-of-control flight characteristics; guidance and control theory; control system concepts; controls allocation/reconfiguration; and control law design. Specific research topics include, but are not limited to: development of technologies which enhance the ability of the flight crew to respond correctly when critical system or component failures occur; prevent related occurrences of loss of control in flight; enable automated responses to mitigate loss of control; and reduce the pilot workload associated with maintaining safe flight. This work area also includes, but is not limited to, modeling and simulation associated with flight dynamics, guidance, and control research and development.

7.4.1 Guidance and Control Technologies

The contractor shall develop guidance and control technologies for operation throughout the flight envelope to prevent loss of vehicle control and recover vehicle control from loss-of control conditions resulting from adverse flight conditions and vehicle or system failures, occurring separately or in combinations. The contractor shall consider and evaluate adverse conditions, including, but not limited to: atmospheric disturbances including, but not limited to wake vortices; weather; internal errors; crew input errors; system errors or malfunctions; external interference; other aircraft; and terrain or other fixed obstacles. The contractor shall consider and evaluate vehicle and system failures, including, but not limited to: control system component failures; sensors; actuators; propulsion system; vehicle impairment and damage; control surface impairment and damage; and fuselage and lifting body impairment and damage. Consideration shall be given to coupling effects between flight control, structure, and propulsion system damage. The contractor shall consider and evaluate vehicle upset conditions, including, but not limited to: operation beyond the normal vehicle flight envelope; unstable modes of motion; stall and/or departure from controlled flight; uncommanded motions due to asymmetric thrust or failures; and out-of-control motions.

7.4.2 Integration with Vehicle Health Management

The contractor shall consider and evaluate the integration of vehicle health management and guidance and control functions, with emphasis on, but not limited to: definition and utilization of diagnostic information for control performance effectiveness assessment and; definition and utilization of prognostic information for predicting and averting loss of control conditions and for life extending control.

7.4.3 Multi-Vehicle Scenarios

The contractor shall develop guidance and control technologies, investigate flight dynamics, and develop simulation concepts and methods related to multi-vehicle scenarios. Such scenarios include, but are not limited to: formation flight, and flight management in a mixed environment containing piloted and autonomous vehicles.

7.4.4 Autonomy and Intelligent Flight Technologies

The contractor shall conduct research in algorithms and software tools to implement autonomy for aircraft and spacecraft, including, but not limited to: pilot autonomy relative to ground control; on-vehicle autonomy to compensate for partial loss of capability; autonomy for unmanned air vehicles flying solo or in formation; and flight deck-based multi-vehicle air traffic control. The contractor shall develop algorithms and software to estimate vehicle state and health and automatically reconfigure the flight control system to compensate for changes in vehicle state and health. The contractor shall utilize adaptive controls, artificial intelligence, machine learning, and statistics-based approaches that account for uncertainties in the vehicle state or control system. The contractor shall develop concepts to facilitate the integration of automated systems with human operators on the flight deck and on the ground. The contractor shall develop autonomous systems for the ground and the flight deck to facilitate implementation of air traffic control measures that manage safety, operational efficiency, and environmental impact.